Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

THE VEGETATION OF CRANBERRY ISLAND (OHIO) AND ITS RELATIONS TO THE SUBSTRATUM, TEMPERATURE, AND EVAPORATION. II

ALFRED DACHNOWSKI

(WITH ONE FIGURE)

The atmospheric influences as ecological conditions for growth

Various theories have been suggested to account for the presence and the relative persistence of this northern boreal flora under present climatic conditions. Some of these theories have been referred to earlier in the paper. Although widely separated from the central region of active bog formation with which the local bog is now only historically connected, its persistence and existence in spite of the climatic changes and animal and plant migration and invasion since the last glacial period, and the fact also that many peat deposits are reported to occur beyond the margin of the Wisconsin ice sheet, suggest that the most significant ecological factors are not to be looked for in the continuation of limiting conditions similar to those which prevailed when a colder climate existed than at present. That bog plants are related functionally as well as morphologically, and that they are grouped and localized with reference to more or less definite conditions of their environment is now a fact no longer questioned. It is also well known that no formation or plant society is likely to be relatively permanent and stationary, for there are changes constantly taking place in the environment as well as among the dominant plants and their associates. In the bog, however, but few successions of plants are in evidence, and the treatment of the vegetational societies from the standpoint of floristics and succession is therefore relatively free from complications. On the other hand, the determination of the factors in bog habitats, and the more detailed study of the dynamics of the process, that is, how some factors are related, their influence and duration—this phase of the problem is still in a state of uncertainty, and the methods of study have been all but satisfactory. When one considers the bog as a habitat, the various causative and limiting factors entering into the plant environment are not so readily distinguished. In connection, therefore, with the analysis of the life conditions in bogs, associated also with the distribution of bog plants, and their conflict with species whose range is more southern, certain meteorological phenomena have been added below.

CLIMATIC CONDITIONS

One of the main objects kept in view during the progress of the investigation on the ecology of Buckeye Lake, and one which seemed to the writer an indispensable preface to both the field and the laboratory study, has been the climate of the region. The general statistics were taken from *Bulletin Q* of the U.S. Weather Bureau Service (**17**), and from manuscript to which access was had by the courtesy of Section Director HAYS of the Columbus (Ohio) Weather Bureau. No continuous series of climatological records have been made on Cranberry Island. The writer made records extending over the period of investigation; these records were supplemented by Mr. DICKEY, whose readings were taken each time the evaporation of the bog habitat was measured. It is felt that the comparative climate statistics given below are generalized data which do not lend themselves to investigation in physiological ecology. Though facing the same set of climatic factors, few of the species forming the flora of the bog island confront the same physiological problems, and hence any conclusions drawn from mere climatic data, without reference to the varying functional responses of the different species of plants, are certainly inadequate. However, the study of the meteorological observations is suggestive mainly in ascertaining the essential differences between the local region and the conditions found in the northern center of bog formation, and in estimating the average temperature and humidity exposure of the plants. The data given in table IV are for Columbus, Ohio; for Ann Arbor, Michigan, where bogs and swamp-lands are found more abundantly; and for Marquette, Michigan, where this type of vegetation reaches a still higher development.

TABLE IV

GENERAL METEOROLOGICAL CONDITIONS

	Columbus, Ohio	Ann Arbor, Mich.	Marquette, Mich.
Elevation	774 ft.	930 ft.	668 ft.
Years of record	31 yrs.	25 yrs.	33 yrs.
Mean seasonal temperature in degrees F.			
Winter	31	26	19
Spring	51	46	37
Summer	73	70	63
Autumn	54	51	45
Annual mean	52	48	41
Absolute maximum	104	101	108
Absolute minimum	−20	−24	−27
Absolute range	124	125	135
Greatest annual range	118		124
Least annual range	89		97
Frost, aver. date of last in spring	April 16	April 28	May 15
Frost, aver. date of first in autumn	Oct. 16	Oct. 9	Oct. 2
No. of days in growing season	176	157	140
Mean seasonal precipitation in inches			
Winter	8.9	6.6	6.1
Spring	10	7.9	7.3
Summer	10.3	10.1	9.4
Autumn	8	7.6	9.6
Annual mean	37.2	32.2	32.4
Absolute maximum	51.2	47.7	42.9
Absolute minimum	26.4	21.1	25.3
Mean annual relative humidity	79	79	80
No. days precipitation	144	138	161
Aver. direction of prevailing wind	S.W.	S.W.	N.W.
Aver. minimum wind velocity	48 miles	......	46 miles

From the data in table IV, it will be observed that the seasonal and annual temperature decreases as one travels from the southern limit toward the northern center of bog vegetation. The climate of the region about Columbus is characterized by a milder winter but a relatively hot summer. The annual range in temperature is comparatively smaller than at Marquette, 102° F. as against 112° F. The normal annual range is here only between 96° F. (35°5 C.) and −6° F. (−21°11 C.), and the greatest departure from the normal variation does not exceed 16° F. The monthly averages for only two months are at Columbus below 32° F. (0° C.), as against five months for Marquette. The normal number of days per annum with a temperature above 43° F. (6° C.), the factor upon which SCHIMPER (**29**) and MERRIAM (**27**) base the boreal limit, is at Columbus approximately 185, that is about one-half of the year, as against 122 days at Marquette. The normal sum total of effective daily temperatures above 43° F. (6° C.), the estimate for which is derived by multiplying the mean average monthly minimum temperature of that period by the number of days, is 10414° F. (2520° C.), as against 6466° F. (1422° C.) for Marquette. The normal mean temperature of the six consecutive hottest weeks of the year, effective also in determining the austral limit of species, is 75°. The warmest month is July with an average monthly maximum of 86° F. (30° C.), as contrasted with 77° F. (25°C.) at Marquette. The coldest months are January and February with an average monthly minimum of 22° F. and 23° F. (5° and 5°5 C.) respectively, as contrasted with 10° F. and 9° F. (12°5 and 12°0 C.) respectively for Marquette. The dates of the latest killing frost in spring and the earliest in autumn, although not the exact limits of physiological activity in plants, or the limits of the growing period of most plants, are nevertheless an unquestionably important factor. Six months of the year are normally free from frost about Columbus.

Though the relation between rainfall and the amount of water needed by plants is of great importance in regard to differences in vegetation, the rainfall and its distribution during the seasons, and the number of rainy days, are of greater significance than is the amount of rain. At Columbus precipitation is quite evenly distributed, reaching an optimum of 10.5 inches (26 cm.) during spring and summer, when the vegetative functions of bog plants are more active, with a minimum of 8.5 inches (21 cm.) during the season of low temperature and in the quiescent period of plants. Columbus exceeds the annual precipitation at Marquette by 4.7 inches (11.8 cm.); the average number of days with rainfall during the year, however, is considerably less than in northern Michigan, 144 days as against 161 days. In the north the greater precipitation is in the form of snow. Marquette has over five times more snow than Columbus, 125.7 inches (315 cm.), as contrasted with 23.5 inches (59 cm.) here. In this vicinity the longer growing season of the plants has therefore correspondingly more of the precipitation available. On account of the higher temperature more moisture is needed, and hence the evaporation also is much greater here than at Marquette. Cold air does not take up so much water as does hot air; consequently the additional amount of water which the atmosphere is capable of taking up to become saturated, that is, the evaporating power of the air, is greater here than at Marquette. The amount of evaporation also depends upon several other factors and conditions; the values of these will be taken into consideration below. Where evaporation is nearly as great as precipitation, the seasonal distribution of rainfall and humidity is a matter of greatest importance, for it is known that scanty rainfall throughout the year, or relative dryness of air and soil during the growing season, favors the development of xerophytic forms in almost any region. The relative humidity of Columbus and vicinity is only slightly less when compared with the north, the percentage of saturation ranging from 79 to 80 respectively. The distribution varies during the year only to a small extent between the month of least and that of greatest normal humidity.

The rate of movement of air currents is, no doubt, of great importance to vegetation, not only because of the direct mechanical effect and the indirect physiological action in increasing the evaporating power of the air, but also because transpiration increases with the velocity of the wind. That wind is an ecological factor of the greatest importance has been emphasized by many authors. KIHLMAN and WARMING regard xerophytic structures in plants as acquired and necessary, on account of strong drying winds in exposed places. Even humid atmosphere when continually renewed leads to strong transpiration, and the danger may be decreased only as protection is provided either through density and height of species, or admixture of a variety of species in a community of plants. The average maximum velocity of wind does not vary greatly between Columbus and Marquette, and hence the influence of wind, though considerable in more exposed places, has apparently little relation to the differences to be accounted for in the character of the local vegetation.

Briefly summarized, the region about Columbus and Buckeye Lake is characterized by a longer growing period with a relatively higher sum total of temperature exposure, a milder winter with normally slight variations, well distributed rainfall, and a relatively high percentage of atmospheric humidity. The local climate is therefore preeminently a deciduous forest climate. The whole region was in its recent primitive condition densely forested. On the other hand, the marked increase of bog development in area and in variety of species in northern localities seems to be correlated with a decline in extremes of summer temperatures and an increase in relative humidity. The general effect is to produce a balanced functional relation, though limited in range, between the amounts of water absorbed and transpired. This phenomenon associated with bog habitats will be discussed in connection with a further analysis of the life conditions obtained in bogs from the point of view of their physiological aridity.

If we take the above mentioned climatic factors into account in the interpretation of local bog conditions, it will be seen that meteorological data in this region are not such as to produce or account for xerophily or for persistence of bog floras. The climatic changes by which a region varies, if severe and varying between wide diurnal and seasonal changes in temperature, humidity, and light, entail naturally modifications in the functions and in the composition of a flora. The vegetation would be tested to the limits of its power of adjustment and acclimatization, and only the forms which had a greater efficiency of responses and had powers of resistance intensified to a new place-function would take up the habitat to the extent in which survival under the modified conditions would be possible. It has been pointed out above that changes in the flora are now occurring and have occurred during the development of the bog island. Many of the former plants have disappeared and are no longer to be found here, while others have survived, hold tenaciously the area under control, and are still constituents of the present flora. Their preservation in this region would seem to be dependent upon less obvious factors than climate. Functional habitat relations, as well as such ecological life relations as are comprised in association, in ecesis, and succession, need therefore the more detailed investigation. In determining these the first component to be considered is the rôle of low substratum temperature. The temperature of a soil is a phytogeographical factor of great significance, but its weightiest importance is in its effect upon the functional activities of roots and rhizomes. Recently the temperature of soils and its fluctuations have received considerable attention. The relationship, however, and the general effect upon plant forms and the correlated functioning are nevertheless but little understood. This circumstance is perhaps the more to be regretted, since, broadly speaking, it seems that the relationship to plant life is the more favorable the more dominating the influence of the physical characters of the soil and particularly the relations prevailing in regard to the physiological water content and efficient temperature.

THE RÔLE OF SUBSTRATUM TEMPERATURE IN BOG HABITATS

During the first few months of field work the device chosen for obtaining the substratum temperatures was the "thermophone." The apparatus is based upon the principle that the resistance of an electric conductor changes with its temperature. In obtaining the temperature of peat soils at various depths, the coils were sunk to the required depth, and their leading wires were then connected with the respective binding posts of the indicator box. A buzzing sound in the telephone increases or diminishes according to the position of the pointer while receding from or approaching to a section of the graded dial. Hence the position is soon found where the telephone is silent. This point indicates the temperature of the sunken soil. The instrument is very sensitive, but very inconvenient for obtaining weekly and monthly minimum and maximum temperatures. Later in the season the investigations were planned for a set of thermographs such as MacDougal described (**25**), that would make a continuous record of the temperatures at any desired depth. The lack of sufficient funds and the failure to secure similar instruments made it necessary to resort to a conventional though less graphic method of measuring the temperature exposure of plants. In the field work of 1908, 1909, and at present, mercurial minimum and maximum thermometers were therefore used. The thermometers for the deeper peat strata were fastened to wooden poles and pushed down into the soil to the depth of 5 feet (1.5 m.). They remained in the soil during the period of investigation except for such short periods of time as were necessary to make a reading. For strata nearer the surface differential and ordinary mercurial thermometers were used, the bulbs of which were pushed down into the peat around the rhizomes of the plants to a depth of one foot (20 cm.) and three inches (7.5 cm.), respectively. The glass stems of the exposed instruments remained shaded from the direct rays of light. The temperatures recorded below, in centigrade, were generally taken on afternoons, usually between 12 and 2 P.M. It should be kept in mind that the maple-alder zone conditions correspond very nearly to those of the tamarack-willow-poplar zone of the northern bogs and swamps, and that a similar relation exists between the local central zone and the open bog-sedge zone of northern bogs.

The readings taken during the period of observation are too voluminous for a tabulated record. Only those of the seasons of 1909 will be given in this place (table V).

TABLE V

TEMPERATURES (C.) IN THE PEAT SUBSTRATUM OF CRANBERRY ISLAND SEASON OF 1909

Station	Jan. 12	Feb. 26	Mar. 29	Apr. 23	May 14	June 11	July 17	Aug. 14	Sept. 11	Oct. 2	Nov. 30	Dec. 28
Central (sphagnum-cranberry) zone:												
Air 1.5 m.	0.5	5	14	23.5	24	26	24	28	27	17.5	14	3.5
Air 30 cm.	0.5	4.5	14	24	25	26	24	28	27	17	14	2.5
Air 7.5 cm.	1.0	4.5	14.5	22	26	29	24.5	28	27.5	17	14	2.5
Soil 7.5 cm.	0.5	1.5	10	12	14.5	21.5	24	25	22.5	16	7	0.5
Soil 30 cm.	0.5	2.0	7	10.5	12	21.0	24	25	22.5	17	8	2.5
Soil 1.5 m.	7.5	6.3	8.5	9	11	16.0	21	22	22.5	21.5	16.5	13.0
Maple-alder zone:												
Soil 7.5 cm.	0.5	1	11	11	16	20	20.5	22	20	14	8	4
Soil 30 m.	1.5	2.0	9.5	10	14	19.5	21	21.5	20	15.5	9	9.5
Soil 1.5 m.	6.5	5.0	8.0	10.5	14	17.5	19.5	21.5	21	19	15.5	14
Lake zone:												
Water 7.5 cm.	1.5	1	13.5	14.5	20.5	26	29	28.5	25	15	6.5	3.5
Water 30 cm.	1.5	0.5	13.5	14.5	20	26	29	28.5	25	15	6.5	4
Water 1.5 m.	1.1	2.7	13	13.8	18.8	22.5	26	26	24	12	6.5	5

A glance at table V shows that the temperature conditions, though comparatively uniform and high throughout the bog island, range somewhat lower in the maple-alder zone than in the central zone. There is a large daily as well as annual range in temperature, but the range is considerably less in the soil than in the air above. The data obtained are sufficient to strengthen the observation made, that in the spring the ice in the central zone melts with greater rapidity, and that a higher temperature results from the greater insolation and the increased absorption and retention of heat rays. On days following a sudden lowering of the air temperature, and also on cloudy days, the temperature of the surface bog water and bog soil in the sphagnum-covered area stands above that of the maple-alder zone. This gain in temperature is cumulative and aids in the penetration of heat rays below the surface. The heat supply is obviously the most direct factor contributing to the substratum temperature, for the variations are associated directly with the amount and intensity of sunshine. The extreme slowness in the maple-alder zone is explained partly by the low conductivity of the partially decayed peat and the lack of a free circulation of air above the soil, but largely by the increasing diffusion of light rays due to the leafing out of trees and shrubs.

Another point of interest is the fact that notable differences are found between the temperatures of the bog island and the surrounding lake water. When we compare the effects of gain and loss of heat between the free water surface of the lake and that of the peat area clothed with vegetation, it will be seen that the temperature of the central and the maple-alder zone remains higher than that of the lake during the autumn and winter months, and that during spring and summer the lake water is warmer at the respective (1.5 m.) depths than the peat substratum. Water has a specific heat far greater than any soil; it retains its heat longer and for this reason is warmer than the peat substratum in spring and summer. On the other hand, peat and humus are cooled more rapidly at the surface by the evaporation of water during the warm days of the seasons. The values of both heat conductivity and diffusion are in general lower in peat than in water, and hence a rapid loss of temperature in the peat strata below the surface vegetation is thus prevented.

A high temperature phenomenon existing in certain places is worthy of special mention. Not infrequently small sheltered areas are found in the central zone bordering the *Rhus-Alnus* thickets where ice never forms in winter. Such temperature conditions would not attract special attention were it not for the fact that usually the temperature is so much lower in the adjacent areas. From a biological standpoint this fact is significant because these conditions favor isolation of habitats and produce a prominent floristic difference. *Wolfiella floridana* commonly occurs in these "warm" pools.

Plants are not dependent so much upon the mean annual temperatures as upon the minima and maxima of temperature encountered, and upon the duration of the vegetation season. To throw some light on the characteristic temperature range occurring throughout the year and within a growing season, the temperature data of the monthly extremes for the seasons of 1908, 1909, and for the autumn and winter of 1907, and the spring of 1910 are appended. As far as the writer is aware, no observations of minima and maxima temperature records within a bog, covering a period of three years, have been carried out thus far. On account of the fact that the present data were obtained at a station whose ecological significance is especially interesting, table VI of the temperature data is deemed worthy of a closer consideration.

We see again that the temperature of the substrata at the different levels is affected less by the alternate heating and cooling at the surface, but in a far greater degree by the progression of the seasons. It increases slowly during May, is stationary more or less during August and September, and begins to decrease fairly rapidly in November. The maximum temperature occurs in July and August, and the minimum temperature is registered in January for the central zone. That of the maple-alder zone occurs in February. Observations have shown that the lake freezes to a depth of 8–15 inches (20–37 cm.), while the bog is covered by ice to a thickness varying from 3 to 5 inches (7.5–12.5 cm.), except for a few places where ice never forms. Consequently, the strata in the bog area below the one-foot level (30 cm.) are well protected from lower temperatures and from sudden temperature changes. When the sun's heat melts the ice and snow, the percolating water derived from the melting ice lowers the temperature of the deeper strata a few degrees in the early spring. The wave of temperature increase falls here slightly behind in March, but the upper strata are not prevented from rising in the meanwhile rapidly above the freezing point. Though of ecological importance as a protective cover during the winter months, and of significance as a bad conductor of heat and in decreasing fluctuations in temperature, the ice and snow do not, therefore, retard appreciably the beginning of favorable growth conditions. The maples and willows of the bog island are in flower about 8 to 10 days later than those on the campus of the university. A persistence, however, in the peat substratum of the winter cold and ice through the summer months is not proved, at least in this region. The records taken at a depth of 5 feet (1.5 m.) below the surface vegetation show a variation in temperature between 3°9 C. and 26° C., i.e., an annual range within 22° C. At this depth only the anaerobic bacterial bog flora is most active. The roots and rhizomes of bog plants do not penetrate beyond the depth of 2 feet (0.6 m.), and the roots of

TABLE VI

MINIMUM AND MAXIMUM TEMPERATURES IN THE CENTRAL ZONE AT CRANBERRY ISLAND, 1907 to 1910

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Air:												
Max......	18.3	15	25	27.2	31.6	33.3	35	35	34.5	30	23.3	19
Min......	−19.4	−24.5	−8.8	−7.7	0.5	3.3	8.3	7.2	−1.6	−5.5	−9.4	−21.6
Range....	37.7	39.5	33.8	34.9	31.1	30.0	26.7	27.8	36.1	35.5	32.7	40.6
Soil: 1 ft. (0.3 m.)												
Max......	4.5	3.3	9	13.3	15	25	27	25.5	25	17.7	13	9
Min......	0	1.2	0	6.6	10	18	17	21.	16	12.5	8	2.5
Range....	4.5	2.1	9	6.7	5	7	10	4.5	9	5.2	5	6.5
Soil: 5 ft. (1.5 m.)												
Max......	13.3	9.2	9	12.2	12.5	17	23	26	22.5	22	20	15.5
Min......	7.5	3.9	4	7.2	9.5	14	16	22	20	18	16.5	13
Range....	5.8	5.3	5	5	3	3	7	4	2.5	4	3.5	2.5

GREATEST RANGE

Air: max. 35; min. −24.5; range 59.5.
Soil 1 ft. (0.3 m.): max. 27; min. 0; range 27.
Soil 5 ft. (1.5 m.): max. 26; min. 3.9; range 22.1.

maples still less. Plants imbedded in the peat at a depth of 1 foot (0.3 m.) are within ranges of temperature from 0° C. to 27° C. The underground growth of the plants continues when the winter temperature in the substratum rises and reaches the gradient from 4° to 8° C. When these soil temperatures prevail during winter for a sufficient length of time, the different stems and buds shoot upward and develop leaves and lengthen their internodes rapidly in the warmer weather of spring. The absorbing organs at 3 inches (7.5 cm.) depth in the peat substratum encounter a mean average of 13°5 C. with an amplitude of more than 30°. In all cases, however, the range of temperature in the maple-alder zone is less than that of the central zone by a difference of at least 6°.

These observations and facts disclosed as to the actual temperatures in the peat substratum of Cranberry Island, and the seasonal changes therein point to the following conclusions:

1. The soil temperature of two plant associations formed about the bog island are slightly different, and each association has its own characteristic temperature range.

2. Of the two plant associations in the bog area, the one more liable to extreme low temperatures in the spring and during the growing season is the maple-alder zone along the border of the lake, and not the more xerophytic central zone.

3. The substratum temperatures as phenomena of the local peat deposits are not favorable to the preservation of bog types, if low temperature is considered to be an edaphic criterion; in connection, therefore, with an analysis of the life conditions in this bog area low temperature is not a limiting factor.

4. A persistence of the winter cold and ice through the summer months is a point not proved either by observation or by registering instruments. The persistence of northern forms in this bog, therefore, has some other cause than low temperature of the substratum. In arctic latitudes, no doubt the most significant factor in determining the character and the distribution of plants, as well as in the formation and preservation of humus material, is low temperature. In the latitudes of Ohio, temperature is not a factor in the process. Neither does the accumulation of humus finally bring about edaphic conditions "too cold and too acid."

5. It is not low temperature that kills invading mesophytes, but the edaphic physiological aridity prevailing in the central zone, which decreases the absorption of water by roots at a time when transpiration and the growth of the plants demand a greater physiological soil-water content.

6. The topographical distribution of plants in the bog is also affected by relations in regard not to low temperatures, but to the uneven physiological water content and the physical condition in the peat substratum.

THE DIFFERENCES BETWEEN AIR AND SOIL TEMPERATURES

We proceed now to a brief consideration of the question whether the differences between air temperature and that of the soil are sufficiently marked during the growing period to prove a factor in the selection of plants for bog areas. To show this relation, data on the corresponding minimum and maximum air temperatures for the period under investigation have been added to table VI. The records were taken from the Climatological Service of the U.S. Weather Bureau at Pataskala, some 35 miles (0.56 km.) distant from Buckeye Lake. They represent fairly nearly the conditions at Cranberry Island on the corresponding period. Additional data are found also in table VIII. Upon comparison it will be seen that during July and August, the months which proved most critical for the cultivated plants grown in the bog area for experimental purposes, the shoots of plants were in an atmosphere varying between 7° and 35° C., while the roots and rhizomes were at temperatures varying between 16° and 27° C., i.e., within a range of temperature differences not less than 9° and not more than 19° C. For a growing season lasting from May 5 to October 1, the average date of the latest and earliest killing frost, the actual differences between the temperature of shoots and roots amounted to 34°5 and 21° C. for each of the absorbing and transpiring organs respectively in the central zone, i.e., within a range of 29° C. It is seen that rapid and passing changes of air temperatures and the occasional extremes do not affect the substratum temperatures. Only average effects prevail and the great periodic seasonal changes. In winter and in summer the minimum temperature of the peat substratum is considerably higher than that of the air. Consequently, the annual mean temperature of the soil greatly exceeds that of the air. The monthly and annual fluctuations of temperature affect the peat area to a depth of 2 m., but they are at no time greater or with a wider range than those of the air. At what depth the mean temperature would remain constant has not been determined.

That the differences between the temperatures of the air and that of the substratum are not as great as is generally supposed, is a fact upon which it is needless to elaborate further. They cannot be looked upon as factors in bog development or in the characteristic xerophily of the sphagnum-covered area in this region, and hence neither the substratum temperature nor the differences between soil and air temperature are of sufficient importance to enter into the problem of bog flora, and zonation or ecesis and succession. The records show that on the basis of temperature as the initial factor the central zone conditions are somewhat more rigorous, and that these conditions are mitigated in the maple-alder zone; but it cannot be claimed that the differences of the plant covering in the two zones are directly correlated with the differences of temperature. With no attempt to minimize its influence, it is evident that for a comparison of habitats, temperature, at least as a single physical factor, is a matter of very subordinate importance on which to establish a causal relation. Those factors acting in conjunction with it demand the greater emphasis. It is questioned, therefore, even for regions where bogs reach their optimum development, whether the coefficient of the differences between the soil and air temperatures is to be looked upon as having a greater value than here in the selection of plants for bog areas, or the production of xerophilous characters.

Whether or not important correlations between the temperature differences and the transpiratory activities of bog and other plants may be expected, a study of the transpiration quantities will doubtless reveal. Work of this character is now in progress and will be published as soon as opportunity permits.

THE RÔLE OF THE EVAPORATING POWER OF AIR

As a preliminary study to the transpiration value of bog plants and to the question also whether the xerophytism and the stunted growth so manifest on maples, poison sumach, and various other plants in the central zone is brought about by an excessive evaporating power of the air, quantitative measurements have been made by the volumetric method to determine the saturation deficiency of the air in three representative stations.

Evaporation is one of the most important factors of the meteorological cycle of a locality. To the student of agriculture and of plant physiology it is a problem the study of which aids in supplying much of the desired information on the growth of plants in irrigated and uncultivated fields. HANN (**16**), who studied evaporation chiefly from the point of view of the meteorologist, has pointed out that the amount of water which the atmosphere is capable of taking up to become saturated is one of the indices of the influence of climate. The highly important observations made by LIVINGSTON (**21, 23**) emphasize the fact that the effect of an atmosphere of great evaporating power undoubtedly influences the geographical distribution of plants, and through its local variations exerts an equally determining effect as a physiological and an ecological factor. The problem of evaporation has been but imperfectly appreciated, and though the bibliography of evaporation is extensive (**24**), the correlation between the evaporation under different conditions has not been satisfactorily formulated. The evaporating power of the air is generally understood to comprise a resultant of temperature, humidity, and wind. But evaporation is very sensitive to soil as well as to air relations, and since a multitude of local factors may influence either of the two conditions, the amount of evaporation integrates the effect of numerous variables. Evaporation is a rather complex resultant, therefore, and in preparing for an investigation which has in view the measurement of the amount of evaporation in plant societies, it is important to keep in mind the several conditions entering into the problem. It is necessary to recognize that the essential details of the phenomenon of evaporation are different in the great variety of conditions, and require separate and special study appropriate to the peculiar conditions. To measure evaporation in a few places in this locality, and then to assign the results to the region as a whole, is a procedure not without its accompanying shortcomings. It was intended to overcome this difficulty partially by measuring the variation in evaporation of the vertical as well as the horizontal vapor pressure gradient in a larger number of stations, plotting the results, and drawing isothymes. By a summation of the evaporation, that of the whole area could be calculated with greater accuracy. The distance of Buckeye Lake from Columbus and the inconveniences as to available time have made it difficult to secure the required observations. However, the problem here dealt with does not concern itself with the development of a formulated expression of evaporation for this region. The purpose at present is to obtain quantitative data on the rate of evaporation, and thus to secure direct evidence as to the relation of the observed evaporating power of the air and the nature of the vegetation. The more detailed study of the phenomenon as originally outlined is now in progress.

The ordinary markets are not prepared to supply the well designed standardized self-registering instruments which have been devised to meet the needs of the Weather Bureau (**26**). For ecological purposes, an instrument is required which can be placed under conditions practically identical with those which the plants themselves endure. For this purpose a small atmometer partly buried in the soil is desirable. Dr. FORREST SHREVE of the Carnegie Desert Laboratory, Tucson, Arizona, courteously left at the disposal of the writer several porous cups of the type as described and used by LIVINGSTON (**21**). The instruments had been previously standardized with an atmometer at Tucson, and since they are similar to those sent out from the Desert Laboratory to various other stations in the United States, the readings obtained may be readily compared. There are certain objections to the porous cups as an instrument in the field study of habitat conditions. The inability of the cup to withstand frost makes it practically impossible to obtain readings for more than the growing period of seven months, and the fact that the instrument does not prevent the direct entrance of rain to the jar introduces an error which becomes very large as the time interval between the reading of the instruments and the length of time and the amount of precipitation increases. The instrument recently described by YAPP (34) and by LIVINGSTON eliminates the error last mentioned, but some weighing method, when available, will probably be more exact than any, since it alone can be employed in the measurement of evaporation from ice, snow, and growing vegetation.

Of the instruments on hand, one was established as a standard in an open lawn freely exposed to the sun and wind on the campus near the University Observatory. It was placed in a manner to obtain readings on the saturation deficiency of the air at a height of 15 cm. above the soil surface. The atmometer remained in the care of Professor H. C. LORD and his assistant Mr. KENDRIG, to whom the writer expresses his warmest thanks for their helpful interest. The records were taken three times daily in connection with the climatological observations called for by the U.S. Weather Bureau Service, and consisted of the reading of the depth of water remaining in a graduated container. The instrument continued in operation from May 21 to September 17, when an accident resulted in the breaking of the graduated retainer. Within a few days the trouble had been remedied and the observations proceeded until October 11, when the first heavy frost occurred.

Another cup was placed in an open and exposed place in the cranberry-sphagnum (central) zone, under conditions similar to those of the standard instrument. It was installed May 14. With the exception of the period from June 11 to July 17, when the total for five weeks was recorded, the loss of water by evaporation was determined at intervals of one week by running in distilled water from a graduate, thus restoring the original water level of the container. Records were obtained until August 21, when it was found that the atmometer had been disturbed. A week later it had disappeared entirely. No attempt was made to replace it by another.

The third instrument stood in the shaded conditions of the maple-alder zone. It was placed near large-sized maples whose cover was relatively dense though open. The reading of this instrument extended uninterruptedly to October 2. During the writer's absence in Europe, the readings in the two plant zones were recorded by Mr. Dickey; they have since appeared in published form (**12**). It is not necessary to reproduce in detail the original observations for the entire period. A series of data from the observations made have been summarized here and the conclusions stated.

Following are the atmometer readings for the several habitats, together with the comparative evaporation expressed in percentage of the standard instrument (table VII).

TABLE VII

Atmometer readings for stations on Cranberry Island and the university campus

1909 week ending	University station	Central, sphagnum-cranberry zone	Percent. diff.	Maple-alder zone	Percent. diff.
May 28	118.8 cc.	97 cc.	81.6	78.1 cc.	65.7
June 4	110.9	92.1	83	60.5	54.5
June 11	88.1	53.3	60.5	27.5	31.2
Five weeks ending July 17	487	349.2	71.7	290.4	59.6
Week ending July 24	151.4	120.2	79.3	77	50
July 31	117.8	69.8	59.2	50.6	42.9
Aug. 7	140.6	69.8	49.6	36.3	25.8
Aug. 14	134.6	82.4	61.2	70.4	52.3
Total evaporation	1349.2	933.8	69.2	690.8	51.2

As was to be expected, by far the smaller part of the total evaporation on Cranberry Island occurred in the maple-alder zone. The annual evaporation within the maple-alder zone is now about three-fourths of that in the open central zone, that is, fully 25 per cent of the moisture is saved by shade-producing trees and shrubs. The evaporation within this zone is greatest in the season from October to May. The difference in evaporation between this zone and the central zone is then at a minimum, but later it follows closely the growth of the leaves in the early spring and their fall in autumn. The maximum difference occurs in June and July. As the seasons advance, the evaporating power of the air in the forested zone varies with precipitation. Wind and temperature are less effective, for as the leafing out of the trees proceeds, and the increased undergrowth also becomes effective in shade and interference with air currents, the retention of the moisture in the air decreases the evaporation rate and the relative humidity is raised. It would be instructive to follow in more detail the effect of the various meteorological factors on evaporation. This effect can very well be seen if the more important factors like temperature, intensity and duration of light, precipitation, wind, soil, and vegetation are referred to individually. But the results are uncertain and suggest the desirability of preliminary investigations in artificially maintained conditions by laboratory methods. In a general way, however, the data show that the inner temperatures of the maple-alder zone are lowered and the temperature extremes moderated, but the extremes in summer temperature much more so than those of the winter. The range in temperature is therefore more affected than the absolute temperatures. The importance of shade producers does not consist alone in their effectiveness to reduce transpiration, but also in their inverse influence upon meteorological factors.

The foregoing table also shows that the greater saturation deficiency was recorded for the station on the university campus. The relative evaporation in the three stations is according to the totals 1349.2 cc., 933.8 cc., and 690.8 cc., the corresponding ratios are 100, 69.2, and 51.2. These differences for the three stations remained fairly constant throughout. The fact that the evaporation rate for the central zone with its numerous xerophytes should be less than that for an area which supports mesophytic forest trees seems anomalous and surprising. Thus for the vegetation on the university campus the furtherance of transpiration by the evaporating power of the air is during some periods approximately two times greater than that on Cranberry Island. This clearly shows that the evaporating power of the air, though furnishing a very valuable criterion for the differentiation between great centers of plant distribution and for the differentiation of habitats, is not an important factor in controlling bog vegetation or determining the character of it.

With the data on hand, it is not difficult to see that the chief

TABLE VIII

VERTICAL EVAPORATION GRADIENT IN THE CRANBERRY-SPHAGNUM ZONE, CRANBERRY ISLAND

Date	Time	Light*	Anemometer; velocity in miles	Evaporation in cc.: cup at 3 in. (7.5 cm.) above ground	Temperature (C.); absolute,			Evaporation in cc.: cup at 1 ft. (0.3 m.) above ground	Temperature (C.); absolute,			Evaporation in cc.: cup at 5 ft. (1.5 m.) above ground	Temperature; absolute,		
					min.	max.	range		min.	max.	range		min.	max.	range
July 30...	6 A.M.	sky clear	34.1	4.86	20	38	18	6.64	20	28	8	9.96	22.5	28	5.5
	12 M.	2 sec.													
	6 P.M.		25.1	11.34	21	37	16	14.94	24	32	8	19.92	26.5	29	2.5
July 31...	6 A.M.		3.6	0.00	8.5	27	18.5	0.00	8.5	27	18.5	1.66	11	28	17
July 31...	12 M.	8–9 sec.	18.1	3.24	16	34	18	6.64	18	30.5	12.5	9.13	17	27	10
July 31...	6 P.M.		12.7	6.48	22	42.5	20.5	7.47	21	30.5	9.5	10.37	24.5	28	3.5
Aug. 1...	6 A.M.		5.6	0.00	8	22	14	1.66	8	21	13	4.56	10.5	23.5	13
Aug. 1...	12 M.	7 sec.	12.1	4.05	15.5	35.5	20	6.64	18.5	32	13.5	7.47	16.5	28	11.5
Aug. 1...	6 P.M.		12	8.91	24.5	37	12.5	9.96	23.5	33.5	10	12.45	25.5	31.5	6
Aug. 2...	6 A.M.	sky clouded	5.4	0.00	13.5	24.5	11	0.00	13	23.5	10.5	2.49	11	31.5	20.5
Aug. 2...	12 M.	28 sec.	23.9	4.81	19	33.5	14.5	7.47	23	31	8	9.96	11	29.5	18.5
Aug. 2...	6 P.M.		25.7	5.67	25	34.5	9.5	7.47	24	32	8	10.19	25	30	5
Aug. 3...	6 P.M.	cloudy	85.1	14.58	19	37	18	21.58	15	37	22	28.22	17	35	18
Total evaporation				63.94				90.47				126.38			

* Time exposure at noon for sensitive photographic paper to standard tint.

external factor which exerts a direct influence on the evaporation at the bog island is the water area surrounding the island. Evaporation from the water surface and from the vegetation produces a vapor blanket, the action of which influences to a great extent the normal range of evaporation under the varying temperature conditions and consequently the rate of transpiration. The evaporation blanket is readily transported over the open central zone, its rate of movement and consequently the rate of evaporation varying particularly with the action of the wind. In the relatively forested maple-alder zone, however, the vapor blanket is more stationary and hence more uniform in its influence. This vapor blanket covers the locality to a definite height vertically. Studies on the phenomena of evaporation of water over lakes and reservoirs (**3**) have shown that the vapor pressure of the vertical gradient varies, beginning nearest the evaporating surface with a maximum, and rapidly diminishing within several feet above the evaporating surface, until it approximates to that in the free air. A few isolated readings confirmed this for the stations in question, as table VIII will show. At first the readings were taken every hour from 6 A.M. to 6 P.M.; later at intervals of six hours. For convenience, the larger time values covering the period from July 30 to August 3 are given here (fig. 8). The amounts are in the ratios 100, 71, and 50 for positions at 5 feet (1.5 m.), 1 foot (0.3 m.), and 3 inches (7.5 cm.), respectively. Hence in general, the lower stratum of a vegetation has a smaller range in humidity variations and possesses an atmosphere usually much more humid than the upper vegetation stratum or the free air above the vegetation level. The data confirm the noteworthy results of the evaporation experiments by YAPP (**34**), and show that the bog vegetation at the lower levels is exposed to transpiration conditions much less severe than those existing at positions above the substratum and those quite clear of vegetation.

But the growth of bog plants and their successful occupation of the habitat do not depend so much upon the total amount of evaporation or the time factor of this exposure, that is, the amount of moisture which the air contains during critical periods of the growing season. The functional activity of the plants is not one of relation to a single factor. In the interrelation of conditions, the real limiting factor to an increase in functional activity is not evaporation or temperature, but the toxicity of the substratum. This fact reveals itself only in experimental tests. Toxicity comes markedly into play when the amount of water available for absorption has reached a stationary value, through the activity of bacterial organisms and other processes. In the field it is very difficult at times to decide which features of the vegetation are to be correlated with low atmospheric humidity, which with variations in temperature and light conditions, or with other factors cooperating at the same time. It is obvious that each in its turn may play the part of a limiting factor, for growth and transpiration are very susceptible to variations in either of these conditions. But in the laboratory the extended experi-

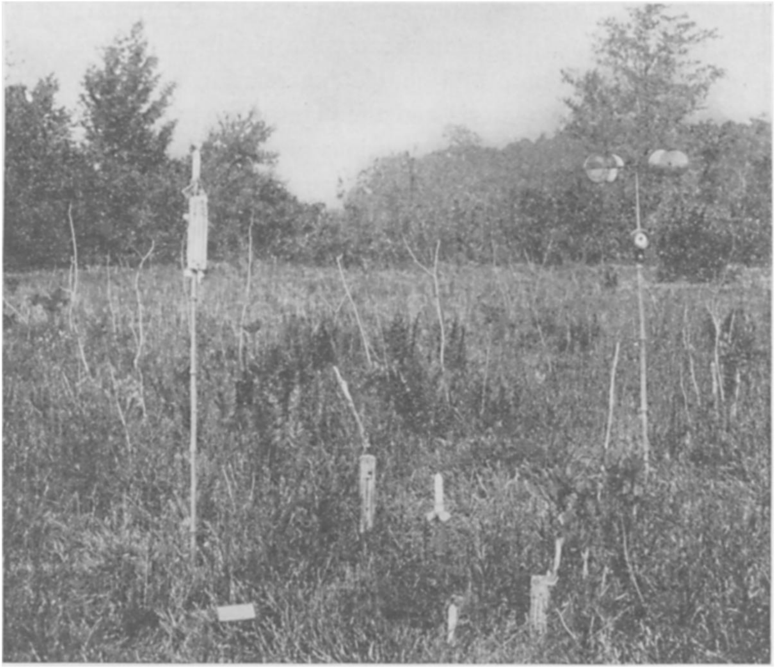

FIG. 8.—Experiment station in the cranberry-sphagnum association; in the foreground stunted growth of *Rhus Vernix;* photographed July 31, 1910.

ments with cereals, legumes, and with plants from the various zones of the island have shown that most plants are unable to provide for a balanced relation between the supply of physiological water which the bog substratum can furnish and the excess of water lost during transpiration even when the temperature or the evaporating power of the air are favorable for any length of time. The susceptibility of the plants to the presence of small traces of deleterious bacterial transformation products accumulating in the surface layers of the peat substratum has been demonstrated elsewhere. An intimate and controlling relation has been found to exist between soil bacteria and the plants growing in the central zone. This has shown itself by various physiological and chemical tests, and by the fact that the presence and fitness of bog plants in the central zone is due mainly to more efficient functional responses to physiological drought. The edaphic aridity prevailing in this zone decreases the absorption of water by the roots in wheat plants about 50–65 per cent, at a time when transpiration and the growth of the plants demand a greater physiological water content. The further quotation of definite examples must be postponed. The ratio of the possible rate of water absorption to the rate of transpiration and growth becomes thus the real determining factor in the bog habitat and in the selection and in the distribution of plants. In all cases cultivated agricultural plants become flaccid and the roots appear gelatinous or as if burned black at the tips. The general dwarfing of roots (see illustrations in **7** and **8**) offers very little efficiency to physiologically arid conditions; nor is the change in form characters of shoot and leaf induced by the consequent lack of coordination of functions an advantage or an adaptation. Resistance to desiccation and the capacity for conserving water are more direct and more efficient responses to the limiting condition which the plants meet. This fact is not necessarily to be taken as valid in accounting for all highly specialized and inheritable structures so frequently met with in plants occurring in these habitats. The alteration of shoots and leaves in response to the stimulation of external factors may or may not increase fitness to the conditions, but it is safe to assume that the capacity for physiological changes and responses controls the survival value of plant forms to a greater extent than has been admitted.

Ohio State University
Columbus, Ohio

LITERATURE CITED

1. Adams, C. C., The postglacial dispersal of the North American Biota. Biol. Bull. **9**:53–71. 1905.
2. Bastin, S. E., and Davis, C. A., Peat deposits of Maine. U.S. Geol. Survey, Bull. 376, p. 61. 1909.
3. Bigelow, F. H., Studies on the phenomena of the evaporation of water over lakes and reservoirs. Monthly Weather Review, U.S. Dept. of Agriculture **36**:437. 1908.
4. Chamberlin, T. C., and Salisbury, R. D., Geology. New York. 1906.
5. Clements, F. E., Research methods in ecology. Lincoln, Neb. 1905.
6. Cowles, H. C., Physiographic ecology of Chicago and vicinity. Bot. Gazette **31**:73–182. 1905.
7. Dachnowski, A., The toxic property of bog water and bog soil. Bot. Gazette **46**:130–143. 1908.
8. ———, Bog toxins and their effect upon soils. Bot. Gazette **47**:389–405. 1909.
9. ———, Physiologically arid habitats and drought-resistance in plants. Bot. Gazette **49**:325–340. 1910.
10. Davis, C. A., Contribution to the natural history of marl. Jour. Geology **8**:485. 1900; also, A second contribution to the natural history of marl. Jour. Geology **9**:491. 1901.
11. ———, Peat. Geological Survey of Michigan. 1907.
12. Dickey, M. G., Evaporation in a bog habitat. Ohio Naturalist **10**:17–23. 1909.
13. Früh, J., and Schröter, C., Die Moore der Schweiz mit Berücksichtigung der gesammten Moorfrage. Geol. Komm. d. Schweiz. Naturf. Gesells. Bern. 1904.
14. Gray, Asa, Address before the American Association. Am. Jour. Sci. III. **4**:293. 1872.
15. Gray, S. M., Improved water supply for the city of Columbus. Ohio Report of 1901.
16. Hann, J., Handbook of climatology. 1903.
17. Henry, A. J., Climatology of the United States. Bull. Q, U.S. Dept. of Agriculture, Weather Bureau. 1906.
18. Jennings, O. E., A botanical survey of Presque Isle, Erie County, Pennsylvania. Ann. Carnegie Museum **5**:289. 1909.
19. Kihlman, A. O., Pflanzenbiologische Studien aus Russisch-Lapland. Acta Soc. pro Fauna et Flora fennica **6**:113. 1890.

20. LEVERETT, F., Glacial formations and drainage features of the Erie and Ohio basins. U.S. Geological Survey **41**: 1902.

21. LIVINGSTON, B. E., The relation of desert plants to soil moisture and to evaporation. Carnegie Institution of Washington, Publ. 50. 1906.

22. ———, Physiological properties of bog water. BOT. GAZETTE **39**:348–355. 1905.

23. ———, Evaporation and centers of plant distribution. Plant World **11**:106–112. 1908.

24. LIVINGSTON, MRS. J. G., An annotated bibliography of evaporation. Monthly Weather Review, U.S. Dept. of Agriculture **36** and **37**: 1908–1909.

25. MACDOUGAL, D. T., Soil temperatures and vegetation. Monthly Weather Review, U.S. Dept. of Agriculture **31**:375. 1903.

26. MARVIN, C. F., Methods and apparatus for the study of evaporation. II. Monthly Weather Review, U.S. Dept. of Agriculture **37**:182–190. 1909.

27. MERRIAM, C. H., Life zones and crop zones of the United States. Division of Biological Survey, U.S. Dept. of Agriculture, Bull. **10**:54. 1909.

28. SCHREINER, O., and REED, H. S., The rôle of oxidation in soil fertility. Bureau of Soils, U.S. Dept. Agric., Bull. 56. 1909.

29. SCHIMPER, A. F. W., Pflanzengeographie auf physiologischer Grundlage. Gustav Fischer. Jena. 1898.

30. SCHWENDENER, S., Die Spaltöffnungen der Gramineen und Cyperaceen. Sitzungs. Preuss. Akad. Wiss. Berlin. 1889.

31. TRANSEAU, E. N., On the geographic distribution and ecological relations of the bog plant societies of North America. BOT. GAZETTE **36**:401–420. 1903.

31a. ———, The bogs and bog flora of the Huron River Valley. BOT. GAZETTE **40**:351–375, 418–448. 1905; **41**:17–42. 1906.

32. WARMING, E., Oecology of plants. Oxford. 1909.

33. WRIGHT, F. G., The glacial boundary in Ohio, etc. U.S. Geol. Surv., Bull. 58. 1890.

34. YAPP, R. H., On stratification in the vegetation of a marsh, and its relations to evaporation and temperature. Annals of Botany **23**:275–320. 1909.